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KONINKRIJK DER NEDERLANDEN

Bureau voor de Industriële Eigendom

Hierbij wordt verklaard, dat in Nederland op 20 oktober 2003 onder nummer 1024573,

ten name van:

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te Molenhoek

een aanvrage om octrooi werd ingediend voor:

"Nano-batterij",

en dat de hieraan gehechte stukken overeenstemmen met de oorspronkelijk ingediende stukken.

Rijswijk, 3 november 2004

De Directeur van het Bureau voor de Industriële Eigendom,
voor deze,

Mw. D.L.M. Brouwer

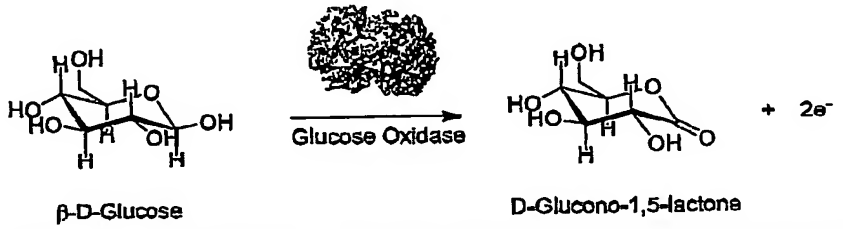
Development of a Bionano-Battery System with Glucose as the Fuel

1. Introduction

This project involves the construction of a nano-battery system for the use on microchips. The nano-battery has to meet certain requirements: (1) It has to be relatively small (1-2 cm^3); (2) It has to be robust and stable for at least a year, and it has to deliver a constant current (~ 80-380 mW). (3) It has to be relatively cheap. Based on technology already present at the KUN, a bionano-battery system will be designed that uses glucose as a very cheap fuel.

2. Design

In our design, the chemical reaction that will be used to generate an electric current is the conversion of β-D-glucose into b-D-glucono-1,5-lactone by the natural enzyme Glucose Oxidase. During this reaction two electrons are released (Scheme 1).



Scheme 1 *Oxidation of β-D-glucose into β-D-glucono-1,5-lactone, generating two electrons*

We have recently designed a system in which the enzymes (Glucose Oxidase) are captured within micrometer-sized vesicles, composed of a block-copolymer consisting of a hydrophobic polystyrene block and a hydrophilic polyisocyanopeptide (Figure 1). The vesicles, which are formed upon dispersal of the macromolecules in an aqueous solution of Glucose Oxidase, are very robust, but still permeable for glucose.[1] The thiophene side-chains can be polymerized, thus providing the vesicles with a conducting polymer outer shell. It has already been demonstrated that a variety of enzymes can be successfully incorporated within the aqueous inner compartment of the vesicles, and that after polymerization of the vesicle shells the enzymes can no longer leak out and are protected from protease degradation. Catalysis experiments with other enzymes (e.g., Horseradish Peroxidase) in these vesicles have confirmed that the enzymatic activity of the included species is retained.

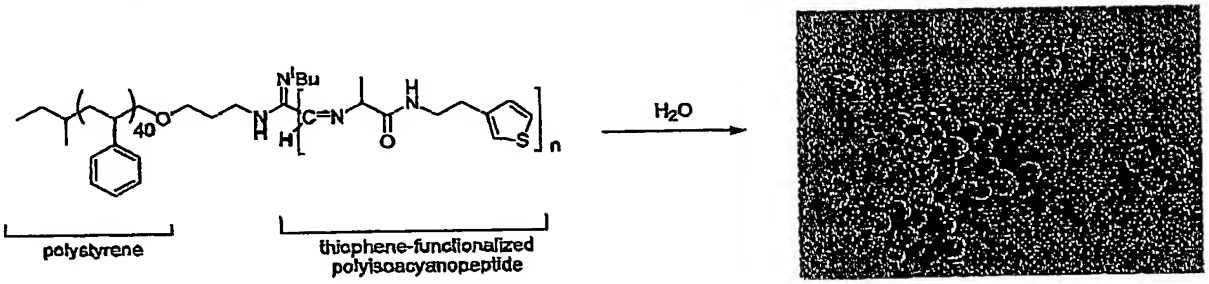


Figure 1 *Chemical structure of the block-copolymer of polystyrene and thiophene-functionalized polyisocyanopeptide, and the micrometer-sized vesicles that are formed upon dispersal of the macromolecules in water.*

We intend to use the enzyme-filled vesicles as microreactors for the glucose-gluconolactone reaction. The electrons that are liberated can be easily accepted by the polythiophene vesicle shells, which also serve as organic electrodes. The design of the battery unit is depicted in Figure 2. A confined reaction chamber of about 1-2 cm^3 is filled with a water-based dispersion of the Glucose Oxidase-containing vesicles. The 'fuel' glucose can be dissolved in this dispersion up to relatively high concentrations. On the top and the bottom of the reaction chamber, two electrodes are attached (constructed of e.g. Indium Tin Oxide (ITO)). Upon the application of a voltage, electrons generated in the battery can be transported to an external capacitor from which a constant current can be liberated to the device that has to be supported.

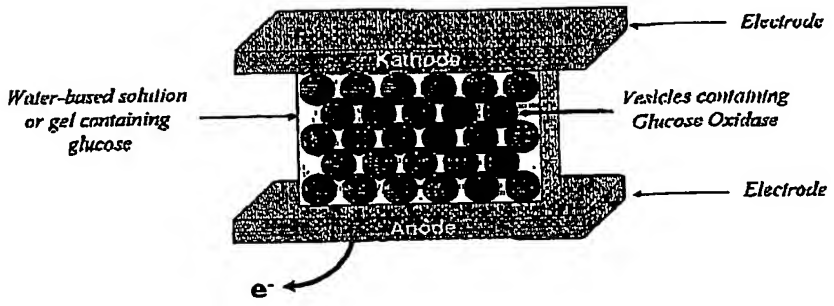


Figure 2 *Schematic picture of the designed bionano-battery.*

The matrix in which the vesicles are dispersed can in principle be simply a solution of glucose in water or in a water-based gel. The pathway of the electrons in the direction of the anode can in this case occur via the vesicle conductive outer shells, on the condition that the majority of the vesicles contact each other (Figure 3a). If this electronic communication is less efficient, a matrix can be incorporated into the solution or gel that carries out the electron transport, for example a conducting polymer (e.g. a polythiophene[12]) that contacts and cross-links the vesicles (Figure 3b).

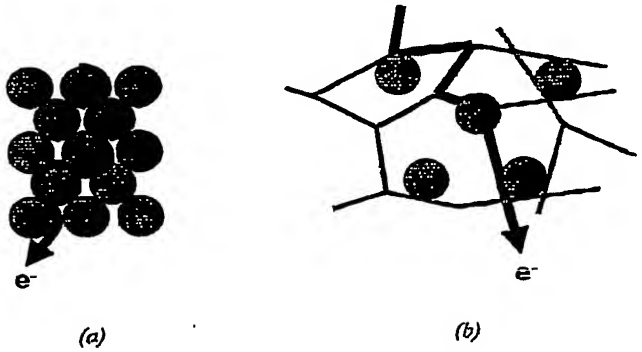


Figure 3 *Two different ways of electron transport pathways. (a) Vesicles contact each other and create an electronic pathway via their conductive outer shells. (b) Vesicles are entrapped in a matrix of a conductive polymer which transports the electrons.*

3. Prediction of performance

For the desired nano-battery an *average* electric current of approximately 200 mA is required, which means that 1.25×10^{18} electrons are needed per second. The following calculations have been made assuming a maximum performance of a cell of 1 cm^3. The required electric current corresponds to 6.25×10^{17} enzymatic reactions per second. Taking into account the reported turnover number of Glucose Oxidase (22,800/s[13]), this means that 2.7×10^{13} enzymes are needed (corresponding to about 4 micrograms). Simultaneously, 2.7×10^{13} molecules of glucose are converted per second (corresponding to about 8 nanograms). Assuming that about 5000 enzymes of Glucose Oxidase are included in one vesicle (an assumption based on other vesicle-enzyme systems), 5.4×10^9 vesicles are needed, which have an average diameter of 1 micrometer.[11] If a compartment of 1 cm^3 is filled with a solution or gel containing 20 volume % of vesicles, this means that 2×10^{13} vesicles are present, a 3700-fold excess of the required amount. This means that the maximum performance of such a system results in the generation of an electric current of 740 A. At the average operating current of 200 mA, and assuming an amount of glucose 'fuel' of 250 mg per cm^3, the battery can operate *continuously* for a period of about 8700 hours (1 year).

Of course, the above system is idealized and at this point the performance-limiting factor is the amount of glucose present. The system will, however, be subject to other factors that can decrease its performance. One can think about enzyme degradation, in particular when the system is operating for a longer time. In addition, an important factor determining performance will be the efficiency of electron transport from the battery to the anode. Several of the parameters of the battery can however be easily varied (e.g. the amounts of vesicles or

glucose, the nature of the matrix), and we therefore feel that there is a considerable chance that the required performance of the battery will be feasible.

CLAIMS

1. Nano-battery system for the use on microchips.